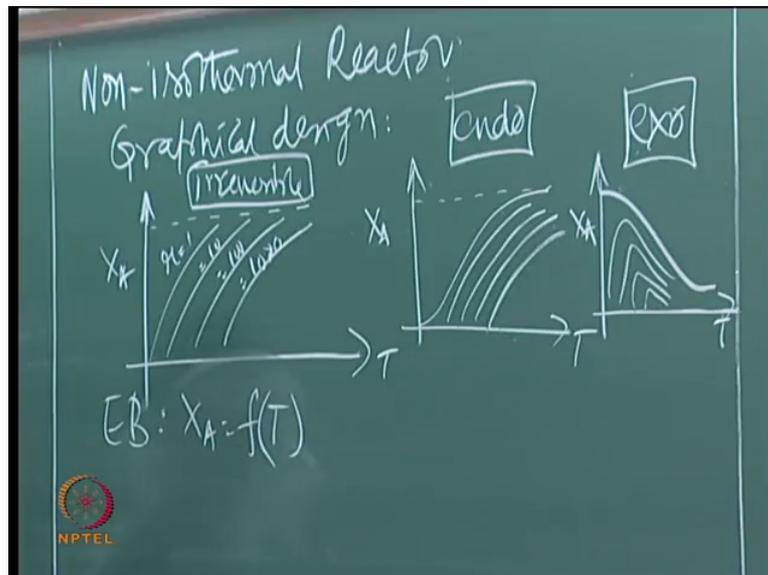


Chemical Reaction Engineering 1 (Homogeneous Reactors)
Prof. K. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras
Lecture No 41
Non-Isothermal Reactors contd. and Adiabatic Reactors

Okay yes this is what we have been discussing and I think you have to again forcibly come to the class that means till now these particular non-isothermal reactor you could have deleted before the examination right so again anyway you do not reload.

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So that is why I think again I have to tell you what we have done and as far as graphical design is concerned what we have generated was X_A versus T this is one way of easy way of doing the graphical design because I have 3 parameters X , T and R the way whatever way I want I can plot it right I can also plot here R versus T I can also plot here R versus X , I can also plot here T versus X is there already R versus T and R versus X okay all these things are possible the other one will be constant but easiest way to use this graphical method is by plotting X versus T that is most convenient way you can also do the other way you know like eating you can also eat food like this right you can also go like this like this like this and then also eat otherwise you can try to eat also with leg.

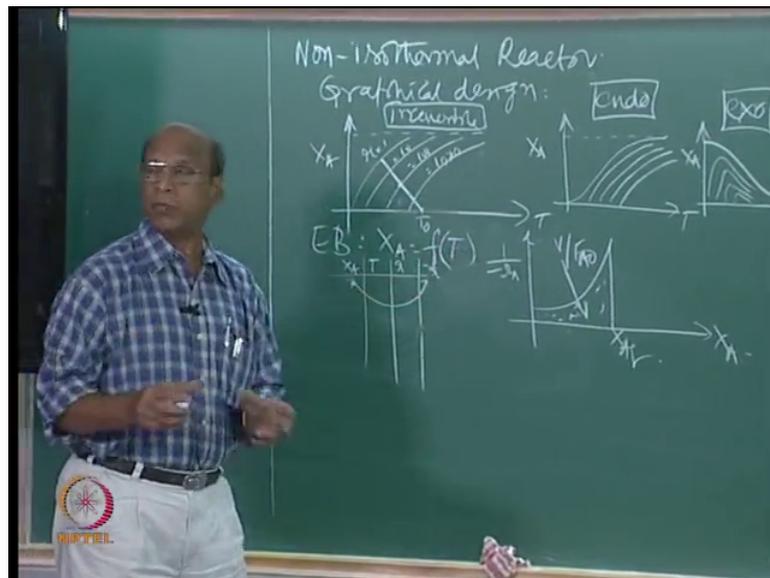
So all possibilities are there so that is the reason why what is the simplest way as engineers? This is the simplest way and we also seen that if we have irreversible reactions what kind of graph you get? Yes what is this? This is R values r equal to 1, 10, 100, 1000 like that right and we have also shown graphs or reversible exothermic reaction and also reversible

endothermic reaction right those graph also we have plotted this is X A versus T okay yes, so this is what? This is irreversible yes and Abdul this is exothermic?

Student: Endothermic.

Professor: Yes endothermic, this is endothermic and the other one is again X A versus T like this yes I mean these are the peaks and this is exothermic these are the graphs and as far as design is concerned we have 2 now find out temperature as a function of x say or vice versa.

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Okay this is X A as a function of temperature this you get from EB I hope you remember EB, EB is energy balance not Electricity Board or something because I think most of the time you may be remembering daily things but here it is energy balance okay good. So now this can be initiate that means it need not be straight line it can be any shape okay that functionality, so you may have curve so when the curve is drawn like this then you have to see the corresponding points and then list out X versus r A where they intersect, now you have a field X, T, r A right. Now if I take some way of drawing okay my line is something like this that means temperature is decreasing as conversion is increasing. This is T not and conversion is increasing but temperature is decreasing. When it is possible? Is it possible at all Swami?

Student: (())(4:38)

Professor: Yes endothermic a reversible reaction okay good, so now I can take these points like this point I have temperature this is the temperature, conversion and R. Next point again I have conversion, temperature and r okay again like that, so when I take all these values like X

a, temperature r and $1 - r$ okay r^A also we can write $1 - r$ good right I thing X^A I have written there, so now this one if I plot X versus these 2 that is the normal way how do a plot when you want to get the volume okay or given conversion you can also get volume or given volume you can also get conversion that is how our equations are that is what we have plotted $1 - r^A$ versus X^A then area under the curve will give you the volume okay, so now when I plot this particular graph what kind of thing I can get? The other day I gave you really crazy thing like this like this it went up and down and all that so now I do not want to give that kind of crazy thing but now this one, so what do I get now? What kind of graph I will get? Simple analytically because here approximate values are given there, what kind of... $1 - r^A$ X^A graph I get yes like what Abdul switched off?

Student: No.

Professor: Then tell Swami is seriously thinking yes now tell me.

Student: (0)(6:37)

Professor: What kind of graph I get?

Student: (0)(6:41)

Professor: Like this? Yes he says like this he is right?

Student: (0)(6:48)

Professor: We are plotting $1 - r^A$ yes (0)(6:53) says straight line this okay what else? All kinds of shape you can tell, what is the correct shape I am asking okay yes. Why so much time?

Student: (0)(7:10)

Professor: See this is where you have to use your brain I said this is where I am very happy to tell you all the time use your brain. You should have that kind of imagination in your brain otherwise I tell you cannot do anything, you cannot do anything. Gopi...

Student: (0)(7:33)

Professor: Decreasing? From where it decreases tell me, how it decreases?

Student: (0)(7:43)

Professor: From where? Here, here, here, so is it decreasing like this or like this (0)(7:50) how it is decreasing?

Student: (0)(7:58)

Professor: Yes Krishna.

Student: (0)(8:13)

Professor: See why do not you approximately put those values and then see it uhh.

Student: (0)(8:23)

Professor: You support Abdullah, it is not election you support or not support. I support Abdul, I support Swami or I support Aria so what is this?

Student: (0)(8:40)

Professor: Decreases?

Student: Increases.

Professor: How it increases?

Student: (0)(8:44)

Professor: Normal rates yes normal goes like this okay yes I think that imagination is very much required. Unfortunately in your schools you have never used brain afterwards and probably you may not even know that there is a thing called brain because everything is stored there you have to do this, you have to do this, you have to do this per day 10 KG books and I think 20 KG homework and the out of that 90 (0)(9:13) done by you mother and 1 KG by a father and over that is all I think some marks they will give and then you pass and come here. Really that imagination is very important and it is not difficult you know you can try that.

See all the brains are not that bad you know they are definitely trainable okay we have not lost hope yet, so that is the reason why now at least you start thinking I have been telling you all correct instead of setting and then seeing Google 4 of you or 5 of you can sit in a room and then okay now Abdul can ask Harishankar okay you plot concentration profile in (0)(9:51) yes why not or you know counter current heat exchanger okay temperature (0)(9:57)

okay and how in a crystallise the concentration gradient within the cake. Why not? What is this useless thing you go and click Google and that fellow will give you 0.3 seconds 1.5 million topics what do you do with that? So instead of that I thing you can ask that okay now I have a plug flow reactor exothermic reaction plot.

What plot? Conversion temperature along the length wonderful uhh but you are not doing that I thing you know just plotting is not that easy you have to imagine lot first of all you should know what is a plug flow reactor and you also should know what is conversion in that and you also should know whether it is exothermic or endothermic so much thinking is required for plotting those values I mean plotting those graphs and you will try that you will do very well in your life later I tell you that imagination that is why I appreciate movie people tremendous innovation and tremendous imagination is only there in movies, ads and music in anywhere you know imagination. All those imaginations have gone long time back absolutely we are training as you know how many people are getting B. Tech degrees in India now 7 lakhs or so per year. What all of them are doing without any imagination and all that what is it that they do?

Student: () (11:24)

Professor: What do they do? Support

Student: TCS.

Professor: TCS yes that is true TCS they may go but I think all 7 lakhs cannot go to TCS I think some more people can go... You know this is what is happening where is your imagination at least after coming here or going to higher studies okay B tech forget over and time is irreversible we cannot go back and get that so that is why at least now the present time use it more usefully, effectively so that you will be happy with yourself as finally are not making me happy okay you will be happy with yourself if you do very well in any subject and that comes only through imagination, imagination, imagination. For everything this imagination is required okay I told you some time back mental screen, the mental screen should be very sharp okay, so that means the moment you close your eyes if I tell you okay I think the same example I gave you okay Bombay, what do you remember?

Student: India Gate.

Professor: Gateway of India or India Gate?

Student: Gateway of India.

Professor: Gateway of India okay that is what Gopi has seen so that is what he remembers right I think anyone Harishankar what do you remember?

Student: (0)(12:37)

Professor: You did not go to Bombay okay you need not go but still you can see some pictures Kareena Kapoor or someone your favourite I do not know you know that is also Bombay okay so movies also that is what you remember most of the time very easily but that means still your mental screen is working the moment you are able to imagine some favourite actress or some favourite actor all that so otherwise mental screen is not active you cannot see them also. You are able to see then? Some people your favourite people okay in which city you have seen?

Student: Delhi.

Professor: What do you remember in Delhi?

Student: Railway station.

Professor: Out of all the places you remember railway station. Anyway (0)(13:34) that imagining the picture there so I think he knows railway station, so like that all of us have that image so similarly the moment I say plug flow reactor that should be in your mind that screen that should flash yes plug flow reactor really Sushmita correct I think if I say tanks in series number of tanks inside this all that should flash in your mind then only you can (0)(14:00) otherwise it is not that easy and those things must be in the mind. I thought I will do lots of things but like this I am wasting my time you know all the time to tell you who make that brain active but the brains is dead all the time I think you know I am not able to make that brain active yes Swami, what should we do?

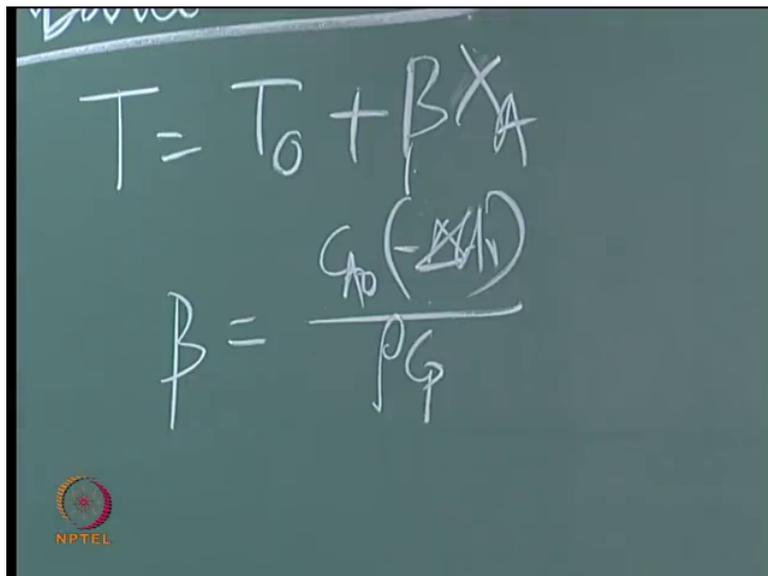
Injections, Injections also you need imagination like what kind of injection? How do you put it? So I think so many people how can I inject? All that in my mind I am telling, so I have to imagine all that so that is why imagination is very important, so this is one of the simplest things what I thought I will ask or continuity sake but I think you took a lot of my time now okay, so now this is $X A f$ if it is volume to be find, so now this area will give me V by FA not okay, so what you are indirectly doing is by doing this is that you are solving material and energy balance equations that is all what you have done, correct? This graphical design at this

point I have a solution for you know this rate right and corresponding temperature and corresponding conversion that is what we are doing.

Instead of solving them on the paper we are now solving them still on the paper only but Graphically you are doing that, right. So that is why even though this is easy to imagine is line need not be linear it can be any shape and procedure is same whatever intersection you have to you know the line goes through then those intersections that X values, R values, E values you have to have and then in fact I can also because it is okay (15:44) it is which reactor? I have not told you in any reactor here. So now you have all the information for plug flow even this one if I ask you what is the temperature profile and conversion profile? Can you plot there? From the same data, you can.

Concentration versus temperature and all that you know conversion temperature along the length right all that information is there on that that is why this graphical design is a beautiful design okay good so this is one part and this is what we have done. Now let me tell you the adiabatic design, adiabatic design also we have done. Adiabatic design means there is no heat yes in or heat out right okay yes that Q equal to 0 so only thing is you will have a nice installation so that you know the heat will not escape and then we are trying to find out what is the relationship between temperature and conversion and we did it for mixed flow reactor to easily understand that, what is the relationship you got for adiabatic system?

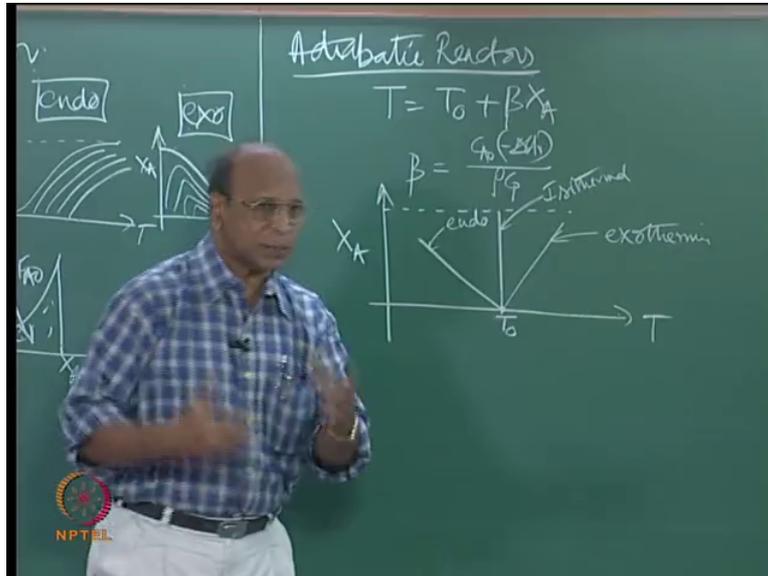
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$$T = T_0 + \beta X_A$$
$$\beta = \frac{C_{A0}(-\Delta H)}{\rho C_p}$$

Adiabatic reactors, for adiabatic reactors are all 3 reactors I think that I will prove later but all the reactors you will get the similar equation T equal to T 0 beta X A where beta equal to C A

not ΔH_r by ρC_p right. C_p is the specific heat okay good so this is the kind of equation you get and in fact this is what also I have drawn and a general graph is available for us this is again very nice information.

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If I plot X_A versus temperature okay, so I will draw the lines and then I will ask you what is the meaning of all these lines okay I may get one line like this or I may get one line like this or I may get... These are all adiabatic lines okay, what is that central line called?

Student: () (18:35)

Professor: Excellent, isothermal line okay, so this is isothermal yes then?

Student: Left is endothermic.

Professor: Left is endothermic excellent, left is endothermic yes the other one is?

Student: Exothermic.

Professor: Exothermic all these 3... Exothermic good right, so now this also gives you a lot of information for example you know sometimes when you have highly exothermic reaction and you want to limit that temperature increase you know what you do sometimes and what are the various ways what we can do and it is not external thing I am asking now it is not external cooling, without external cooling also to some extent we can control the temperature what do you do? Question is clear or just something I am asking yes question is that I have an exothermic reaction and I do not have any means of removing heat or adding heat okay here

removing heat exothermic reaction but still I can reduce the temperature to some extent by some other means I mean various possibilities are there.

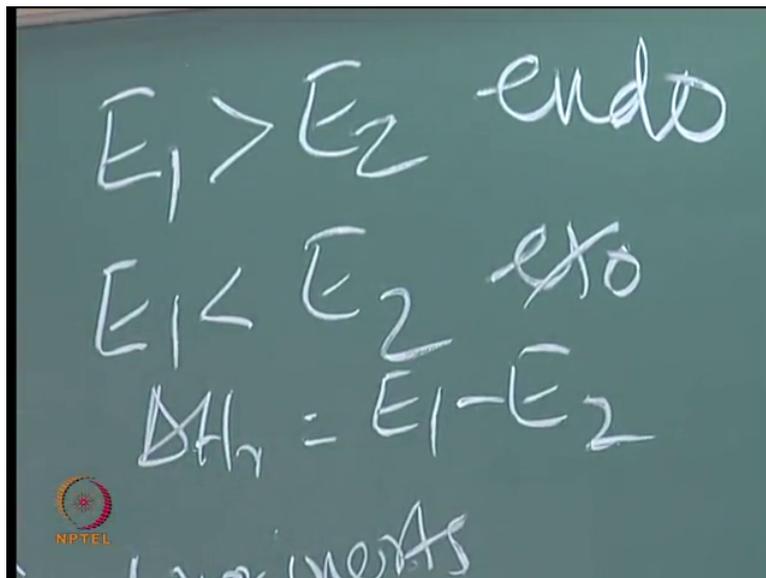
Student: (0)(19:54)

Professor: Yes recycle is one thing but recycle I thing yes other than recycle? In fact recycle is what (0)(20:04) is telling exactly same thing okay it is now adding almost like energy, correct? Because products once it is already formed and it is not again nothing is happening there is not again going to reactants, it is not reversible reaction okay, so that is why it is the recycle reactor or most of the time we also use inert gases particularly for gas phase reaction where catalytic reaction particularly and the catalytic stage very (0)(20:34) due to temperature, so you would not like to anywhere in the reactor reach high temperatures and if they reach high temperatures then the catalyst will be spoil, so that is why deliberately you add like nitrogen okay, so that means how this line moves by the addition of inert so that means... yes what is becoming I think assuming that I have added lots of inert in which direction it moves?

Abdul think I said. Yes not this side it has to go to this side because idea of adding inert is to reduce the temperature or to make almost isothermal, so that is why by adding inert you can bring it here, this is adding inert okay so like that all possibilities are there I think this is a very nice graph, how do I get is just by energy balance only this is the equation, now depending on your slope negative or positive then you will have either this side or this side, right and last time you know you are getting confusion and all that, so for that exothermic reaction and endothermic reaction. For endothermic reaction E_1 is both are positive only E_1 and E_2 there are 2. E_1 is

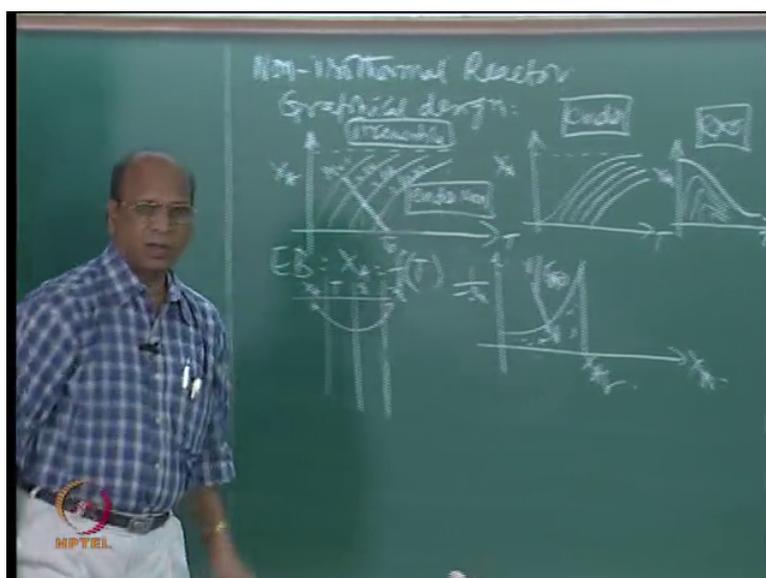
Student: (0)(22:12)

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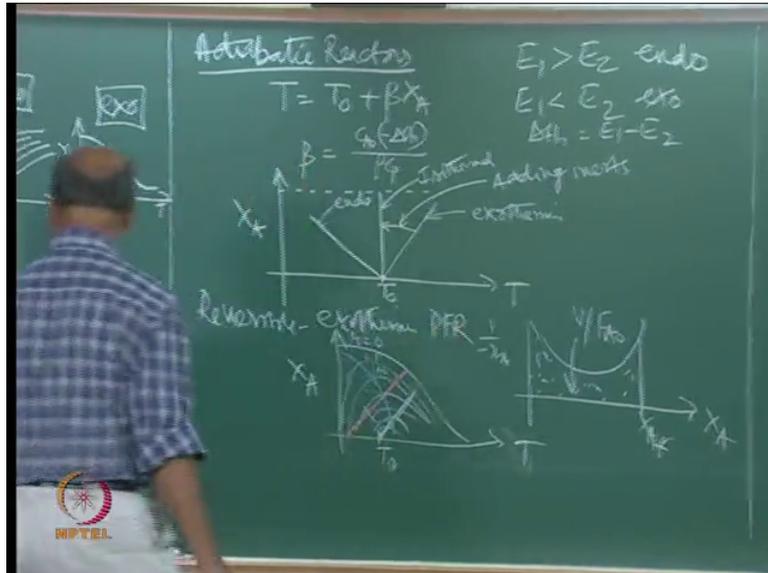
Professor: Yes please make a note of that E_1 greater than E_2 endo and E_1 less than E_2 exo and always ΔH_r defined as E_1 minus E_2 the other day I think you are trying to say so many things, right so that is what... I think delta also let me write, ΔH_r is written as E_1 minus E_2 depending on this as sometimes you know the conversion is minus ΔH_r equal to a positive quantity is exothermic in our convention the way we write the data okay good. So this is the one which is very nice information, now taking these things if I have an endothermic reaction adiabatic system okay are an exothermic reaction and how do you actually design the reactor? So this already this is what?

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This is in fact is endothermic irreversible is there already endothermic reaction okay if it is exothermic reaction and reversible for example so then (0)(23:26). Reversible exothermic reaction, reversible exothermic reaction and I have an adiabatic reactor okay yes first of all we have to go to this one which is reversible exothermic reaction good yes.

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So reversible exothermic this is endothermic already we have given, reversible exothermic okay, so let me draw those lines this is T versus X a, so then you will have like this then uhh yes, so those are the rate lines and this is r equal to 0 equilibrium line this is what I have asked that 0 (0)(24:22) yes so this is r equal to 1 maybe or 10 so et cetera. Okay tell me now what I have to do here? What is the procedure? Adiabatic reactor I just want to design, adiabatic reactors.

Student: (0)(24:45)

Professor: Yes T not I know T not is somewhere here straight line means like this okay I have done straight line, so what is the meaning of that?

Student: (0)(25:06)

Professor: Exothermic adiabatic, is it straight line vehicle?

Student: (0)(25:12)

Professor: Oh my God I think (0)(25:15) you have here I said you have just here exothermic endothermic I have not even removed this okay but you deleted this graph from your brain

and you are not even able to see this when it is there. I am very clearly telling that reversible exothermic reaction for all exothermic reactions temperature should increase with...?

Student: (0)(25:37)

Professor: Yes with conversion, right with conversion temperature should increase, so I have to draw a line something like this okay. Can I touch this line? Imagine (0)(26:01).?

Student: No idea.

Professor: What is no idea just think I said I mean what is that r equal to last line?

Student: (0)(26:12)

Professor: 0 Lane yes if I go to 0 Lane what will happen to me? Why I cannot go?

Student: (0)(26:19)

Professor: It is a reversible reaction but in design what will happen? Now okay what is the procedure now uhh now what is a procedure? Okay assuming that I have drawn this line yes there is a new line now okay so this is the line now, now what is the procedure? What is the procedure?

Student: (0)(26:51)

Professor: Yes again I have to find out now for each yes there are many like this, right. So yes I should now list out as shown here X_T and then rate and then take $1 - r_A$ and then finally plot $1 - r_A$ versus X_A okay, so is there any limit for me or I can take this value, this value, this value, this value, this value, this value there are no other values further otherwise I also could have...

Student: (0)(27:22)

Professor: Yes I cannot draw these, I cannot draw beyond that I cannot even touch it. The moment you touch what will happen?

Student: (0)(27:30)

Professor: You go to infinity okay if you go to infinity you cannot come back that is all I think you know that is infinity okay so that is the reason why somewhere we have to stop that is a wonderful point I want to tell you okay somewhere you have to stop, where? Actually

this line goes through many interesting points, anything we can discuss here okay. Now this is the highest rate, this is the lowest rate, this is 0 okay, so now when you are moving like this what is happening? It is first seeing anyway this side also you will have like this right? So at this point it is touching like this and then next and then next and then how it is going now?

Student: () (28:24)

Professor: Yes in fact if I move this line or easy explanation okay from here if I draw the line it is 1st going through because here this is not that easy to explain because the way I have drawn but now when I draw this line here okay let me draw with red ink yes so are T not normally we will have low temperatures right to start with I mean whatever possible reaction temperature we will have. Then it is now crossing the lower rates, is it logical?

Student: Not logical.

Professor: Why not logical? Why logical?

Student: () (29:14)

Professor: Yes at low temperatures are rate will be less so that is why it starts with low rates and now there are 2 things now concentration as well as temperature both it is exothermic reaction, so then what happens? Concentration falls a little bit but a temperature increases because of exothermic nature Aria following? That means heat is released and that heat increases the temperature of the bulk fluid, right? The fluid which is moving, so then you will have increase in temperature. This temperature increasing now rate of reaction, correct? Minus r_A equal to $K e^{-E/RT}$ into C_A , right?

Temperature increases the rate of reaction even though concentration is a little bit less but the functionality of this temperature is exponential whereas that is only 1st order or 2nd order okay C_A or C_A square, right. Normally C_A cube maximum otherwise you cannot go beyond that right, so then temperature okay that heat released again increases the temperature, now this temperature uhh you have some rate sorry some concentration, now concentration is falling a little bit but temperature is trying to compensate, so like that this combination of initially small temperature and high concentration.

After sometimes both concentration... Concentration decreasing anyway the combination of concentration and temperature may reach the highest rate and then afterwards what is happening? Even though the temperature is high concentration is folly okay, so you will not

have again more rate of reaction temperature is there but concentration is not therefor reaction to take place that is why this line goes through all that history. Initially you have some low rates then slowly the rates are increasing and maybe this is the highest rate for this line this one is the highest rate for this line and afterwards it is now going to...this is low rate, this is low rate, this is low rate yes other side it is crossing for the lower rate okay.

So now initially increased reached maximum and then going to again lower rates and then finally it touches 0 that means if you are using that 0 value for design you cannot design because infinity volume you get. Now tell me if I plot X_A versus $1 - r_A$ versus X_A if I plot what kind of a line I get, that plot you see the imagination I say imagination, imagination I think my explanation you could follow right Swami? Initially when reactants are introduced time T equal to 0 T not is not very high T_0 is not very high concentration is high reaction is taking place, right? So when the reaction is taking place heat is released because it is exothermic heat okay, so that heat increases the temperature even though concentration falls a little bit.

Now the combination of this temperature and concentration rate will be more, so similarly you go on you know temperature increases and concentration falls a little bit but that combination is still more rate, more rate it reaches a maximum, so beyond some point that concentration falls so much right so then you will not have high rate then it has to go to in fact yes lower rates and that highest rate line is okay blue highest rate line is this you know this maximum that is the highest rate okay. You have all the rates but these are the highest points in fact this is the locus of maximum rates that you have to cross, so once you cross once you are here it is increasing once you cross this the rates are decreasing, so now tell me if I plot $1 - r_A$ versus X_A what kind of graph I get? Like auto catalytic U shape you get okay so now is it mixed flow reactor or plug flow reactor?

Student: (())(33:48)

Professor: No I am not talking about this, this line it cannot be combination what do you mean?

Student: (())(33:55)

Professor: It is plug flow reactor. What we have discussed is all this is for plug flow reactor right. In plug flow reactor only when it enters you have a position where temperature and concentration (())(34:08) gives a rate yes change. Then afterwards another position, another

position, another position okay how many positions you have in mixed flow, there are no positions straight away you have to go to 1 point but that will be on this line same line but at one point that point corresponding to what conversion you are trying to find uhh not trying to find you are fixing to find out the volume anyway that will come a little bit later, so now what area I have to take?

Student: (())(34:40) for the lower rates I mean the line is cutting that curve point and 2 conversions we are getting.

Professor: Conversion is...yes that is true that is why that U shape that is why simply parabola okay, so now what area I have to take Abhijeet. Are you convinced with that this is a plug flow reactor?

Student: (())(35:11)

Professor: Why because this line places each and every position where there is a concentration and temperature in a plug flow reactor okay yes along the length of the reactor...actually you can now get more and more visualisation what is happening in a plug flow reactor? So at every cross-section you have we say that different rates and all that now we are also adding temperatures and what you are showing here is the average of all that rates. So now this is the final conversion which I have fixed so what is the area I have to get?

Student: (())(35:53)

Professor: That is all area under the curve, so it must be something like this yes. This is V by $F A$ not, so now exothermic reaction we have discussed and also endothermic reaction we have discussed okay for plug flow. Even recycle also it is very easy now for me right, so recycle means I will have here only it is not starting from X equal to 0 it is only starting from X equal to some value. How do I find that value? You have any question for recycle reactor $X A 1$ equal to...you should know recycle ratio definitely so that the recycle ratio r you can substitute and $X A F$ is given because you are not trying to find out volume that means $X A F$ you know right so you can know $X A 1$ and from that point is line is valid from that point to $X A F$ value right. Now one thing what you can notice in this graph is that if you start with high temperatures T_0 . If T_0 is high is that the advantageous or disadvantageous?

Student: (())(37:09)

Professor: Rate will be high okay yes then that is immediately seen but when you move along is advantageous or disadvantageous?

Student: Advantageous

Professor: Why is it Advantage?

Student: (0)(37:21)

Professor: Yes so the conversion which you can attain is only this much that means only this much, so maybe 40 percent whereas if I go here and then draw the line advantages or disadvantages?

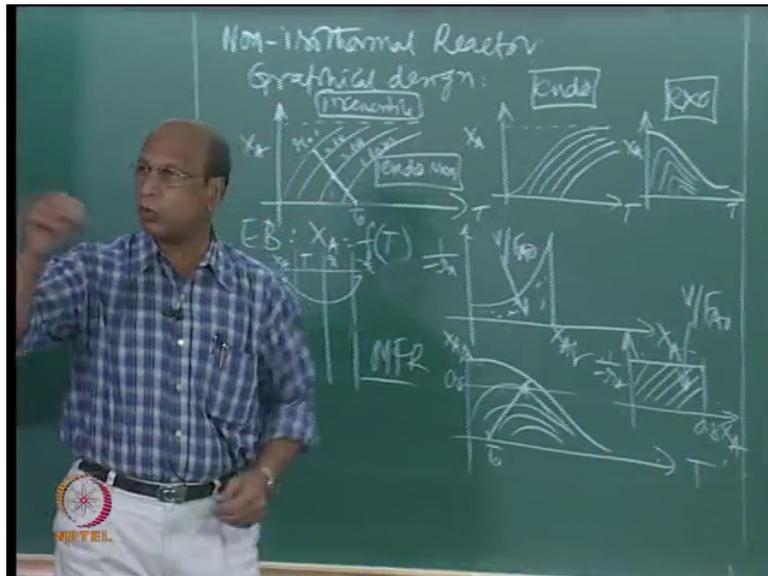
Student: (0)(37:39)

Professor: Yes why it takes time? I think it is not take time it takes volume.

Student: (0)(37:46)

Professor: Because now here I am in the presence of very small rate not high rates, so naturally $1/r$ will be very large correct, so then I will have large value of reactors so that is why this is a beautiful optimisation program where you will start? Is it one reactor or is it 10 reactors? How do you really use this information to design the most optimum reactors? You see how much information on that simple innocent looking graph, it is looking really innocent right but you should know what is innocent first of all okay yes so much information on that okay.

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Now let me ask you question about mixed flow reactor I have the same thing mixed flow let me draw separately again this is reversible PFR if I have mixed flow MFR yes so this is almost constant, this is X_A this is T then I have like this, like this yes because I need only one point where because mixed flow there is no positional change okay (0)(39:17) the moment it enters you will have only one concentration one temperature or 1 conversion and which is equivalent to X_A .

So how do I now calculate my volume for us? And do not immediately conclude here uhh someone was telling that recycle reactor, we have not drawn this for recycle reactor we have only drawn for adiabatic PFR we are talking about all adiabatic okay right because you saw the shape and then you try to put one reactor another reactor you will never get that right in this case because it is the rate information which we got after imagining that we have plug flow reactor then only I will get this line and it is starting from here or here are going through all kind of rates initially low afterwards again low in between high.

So that is why you get that change because I think autocatalytic reaction probably you like so much anything you see that is your autocatalytic reaction not immediately draw first MFR and next PFR do not do that okay so all this history has come only because of this particular line okay good now mixed flow quickly I thought of doing so many things uhh how do I draw here my line so that I will get the volume again here like V by $F A$ not I had also find out V by F . Sushmita, what is known to us? Conversion yes okay, so now tell me?

Student: (0)(40:54)

Professor: Excellent you have to first draw the straight line okay good then now I draw the straight line then?

Student: () (41:08)

Professor: Yes T not excellent I know T not is here now what I should do? How do I locate that point? Straight, straight means like this again...we are discussing about this is what 1st of all which reaction exothermic or endothermic?

Student: Exothermic.

Professor: Yes exothermic so that means that line, so I know the slope I have to plot simply with that slope that line, so now how do I calculate volume? So actually yes even though I draw this line but I do not have this point, this point, this point, this point here I have only one point because it is mixed flow, so now show me how do I calculate now volume? Yes what I have to plot here this is $1 - r_A$ versus yes so how do I get it?

Very simple, this is X_A () (42:25) for me right because X_A is fixed point for example so that is the line I have here 0.8 uhh then this line is cutting this line at this point, so if r_A equal to 1 there $1 - r_A$ equal to also 1 that is the point which I have to locate and then simply multiply. () (43:00) is 110 percent right simply locate that minus r_A , $1 - r_A$ multiplied by $X_A F$ because that is nothing but a rectangular area correct? This is $1 - r_A$ that is what is the point okay r_A and $1 - r_A$ this is $X_A F$ point simply do that, so this is how we will design our reactors using graphs.

Student: () (43:34)

Professor: No but which line cuts how do I know? Which are cuts?

Student: () (43:40)

Professor: Which point? This point. How do I know?

Student: () (43:45)

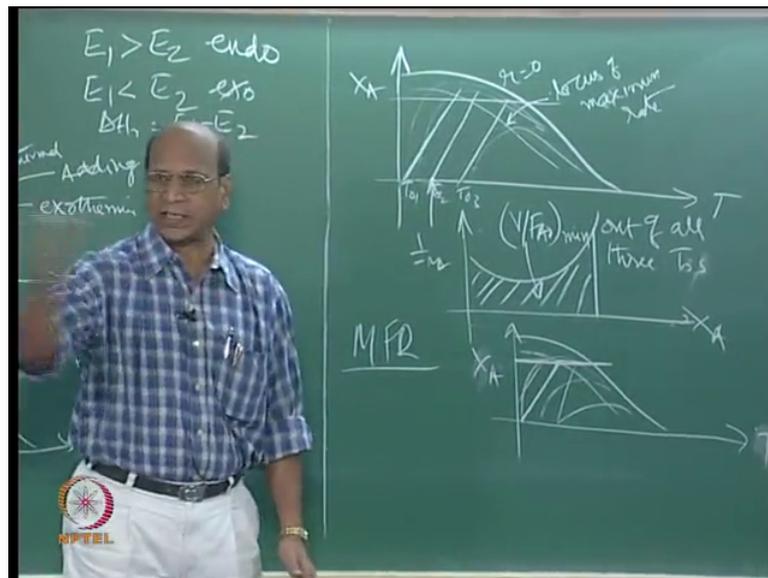
Professor: Unless I plot this how do I know?

Student: () (43:50)

Professor: After that yes that is fine after that...this graph your talking that is fine no problem but I am thrilled with graphical design (43:58) okay yes so that is why this is again V by F okay, so now you can see that we have this design blindly saying that okay I will just go T_0 I know and also I know the slope. Slope is nothing but you know the properties of C_A not and $\rho C_P \Delta H_r$ and all that so I know the slope I draw the line and if it is plug flow I will know the history of all the rates I will note down all the rates and $1 - r_A$ versus X_A graph will give me the volume.

If it is mixed flow only 1 point I will locate and then get all these but most of the time if you want to because always we will try to optimise in our life whether it is a reactor or your own life I thing you have to (44:46) okay. So now one question what you can ask is that (44:50) of which you have chosen or someone given is it really good one? So if it is not that means what is meant by good one, for that T not volume should be minimum, volume should be minimum can I locate that with the same information can I locate that?

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So again I will draw this graph here, so this is X_A versus T reversible exothermic okay the endothermic and all that we will discuss later and you have okay I will also now simply drawing this line where this is r equal to 0 equilibrium line and this one is locus of maximum rates Max okay, so that line I have and of course in between I have all this you know for example this will go like this next one will go like this somewhere here will go not so much uhh like this, so all the lines here they will not cross okay please do not take that yes, so that is what I have now how do I locate?

I think maybe it is difficult for you to tell this particular part and even now what I know is conversion right? We are trying to find out volume and the reverse problem is simply finding out conversion if volume is known, so now I know conversion so then I will just draw the line okay and now what I have to do? I have to now locate my T not so what I do is I randomly choose okay one line here, another line here, another line this is T not 1, T not 2, T not 3 et cetera but they are parallel lines because ΔH_r is constant and CP and all that is not change in temperature, so what I do now is I will do the same exercise for all those lines.

I will take all the rates which are intersecting corresponding conversions then I will have a graph like this. I know one V by $F A$ not right, now I will come here again do the same thing, now I will have another we by $F A$ not and then I will go here and then do the same thing again. So I will have this (47:25) basis which will give me the minimum area or the volume, minimum area you understood? So that means probably this will be the correct one right and all the time you get for reversible exothermic reaction this kind of parabola type curve.

So this area...so this is $1 - r_A$ versus X_A so you will get like this so the area V by F_A not minimum out of all 3 possibilities. Minimum out of all 3 T nots okay so actually with experience you can really start either here or here or here you can automatically start. Okay because first of all you have to fix the conversion right and we know that definitely if I go this side volume will be minimum why rate is high but your conversion will be only 10 percent, so that is why you draw the line first conversion line okay I am coming Avinash okay then you choose T not values and then draw the lines, so then you will find out the minimum V by F_A not minimum for this, for this, for this which one is the minimum? Then that is the correct T not so that means you can even fix now T not okay yes and normally this cannot give you T not because okay here as per this graph is concern what kind of graph you get for this possibility? Could you get this kind of graph?

Student: () (49:27)

Professor: Yes because you not cross the maximum that means you are only increasing rates the other side decreasing has not come okay, so I think definitely the T not may not be valid, so by () (49:42) one can fix this okay Avinash were asking something.

Student: () (49:48)

Professor: Yes because now I also asked question how do I find now optimal T not, optimal T not to which gives me minimum value so that is why again I started () (50:05). Now I have to start again next one is MFR. What do I do for MFR? I have the same graph X_A versus T okay same thing again reversible this is the maximum () (50:27) yes so like this you have. Now I have fixed the X_A okay how do I find out? Avinash now I have to look at my T not which is the optimal T not and this is for mixed flow, how do I do it? Equation is same different temperature you have to draw the line but where does that cut here you have the nice thing. From your mind can you tell where is that cut? Which line it cuts?

Student: () (51:19)

Professor: Maximum?

Student: () (51:23)

Professor: Yes excellent and where is that yes so the point which is passing through this must be giving me optimal T because this is the maximum () (51:35) this is the one right so if you do not know that and you can draw a line here you can draw a line here and then try to find

out which one will be (51:45) this will be the maximum rate or this is a not this will be the maximum rate and that depends on the slope that slope you have parallelly we just move like this like this, so it cuts this line, this line at this point. In fact Rahul me say that sir you do not have to do all that, correct because the moment you draw the line horizontal line it cuts this line and you know what is the point?

You do not have to do trial and error okay I am telling trial and error because we started with the trial and error so same and of procedure I am trying to tell okay so if you are smart enough you can easily find out that is the maximum rate locus so it must be on that because that $1/R$ must be minimum, correct? For V by FNR so then you will get I think now I am afraid to draw the graph okay, so there also I can take correspondingly that R $1/R$ versus X A rectangular area will give me minimum volume okay excellent we will stop here. Tomorrow class what we will do is, is there an optimal temperature progression for exothermic reversible, exothermic endothermic are sorry irreversible endothermic exothermic, reversible endothermic, reversible exothermic.

Is there an optimal progression of temperature that means we are not talking about one reactor we may be talking about a series of reactors. That gives you a very clear picture I asked you one question why a multi-bed reactor is used for that (53:26) for SO_2 to SO_3 3 reactors are used in series okay. Now you will know the in this discussion why that is used there? You heard of that SO_2 to SO_3 reaction okay it is adiabatic reactor and adiabatic multi-bed reactor for sulphur dioxide production in this step SO_2 to SO_3 okay so when you discuss tomorrow you will know what is that reason exactly why people use that okay.